DESCRIPTION

FRACTURE PREDICTION DEVICE FOR SPOT WELDED PORTION, METHOD OF THE SAME, COMPUTER PROGRAM, AND COMPUTER-READABLE RECORDING MEDIUM

Technical Field

[0001] The present invention relates to a fracture prediction device for a spot welded portion, suitable for use for a spot welding of a structural member for an automobile, in more detail, for predicting a fracture of the spot welded portion of a member at a time of a collision deformation, to a method thereof, a computer program, and a computer-readable recording medium.

Background Art

[0002] In recent years, it becomes an urgent problem for an automotive industry to develop a vehicle structure capable of eliminating an injury for a passenger at a time of collision. The vehicle structure excellent in such a crashworthiness can be realized such that an impact energy at the time of a collision is absorbed by structural members other than a passenger section, and a deformation of the passenger section is minimized to thereby securing a survival space. Namely, it is important to make the structural members absorb the impact energy.

[0003] A main structural member absorbing the

impact energy at a full-lap crash or an offset crash of an automobile is a front side member. In the front side member, the cross section of the member is closed by a spot welding after the member is formed by means of a press forming and so on. Generally, this front side member is collapsed to thereby absorb the impact energy. It is important to stabilize a buckling mode and not to make it bend or fracture halfway, to improve the absorption of the impact energy.

[0004] There are problems such that a fracture occurs from a welded point at the time of buckling to cause an unstable buckling mode and the absorption of the impact energy deteriorates, if a spot welding interval, a nugget diameter, and a welding condition are not optimized to stabilize the buckling as for the above-stated spot welding of the member.

[0005] Non-Patent Document 1: Expository Papers No. 9705JSAESYMPOSIUM "New Forming Technique of Vehicle Structure"

Non-Patent Document 2: JIS Z3136

Non-Patent Document 3: JIS Z3137

Patent Document 1: Japanese Patent Application Laid-Open No. Hei 6-182561

Patent Document 2: Japanese Patent Application Laid-Open No. 2002-31627

Summary of the Invention

[0006] Conventionally, a condition has been

investigated to solve the problem, in which, for example, a member is buckled stably without fracturing at a welded point by manufacturing members experimentally while changing spot welding intervals variously, and performing a crash test as shown in Non-Patent Document 1. However, in the above-stated method, trial and error is required in which experimental products are manufactured by each automobile, or by each member to perform the test, and therefore, there was a problem such that a manufacturing cost becomes high and a long time is required to design.

[0007] Besides, in Patent Document 1, a fracture prevention structure of a welded portion of a floor panel where a load is applied is proposed, but it is a structure only for the floor panel. Therefore, it still required trial and error by the experimental products to obtain a spot welding method in which fracture at the welding points is prevented in every impact absorbing member, and the impact energy is absorbed by the stable buckling.

[0008] Further, in Patent Document 2, an optimization of the spot welding interval is proposed, but it is only a simple index as for individual spot welding strength, and it is not an accurate prediction for the fracture as it is. Therefore, there was a problem in which a design based on an accurate fracture prediction for the spot welded portion was impossible.

[0009] As the index of the strength at the spot welded portion, a shear tension test and a cross tension test defined in Non-Patent Documents 2 and 3 are representatives. There are reported examples under various test modes assuming various load states other than the above, but in general, a shear tension test value is treated as a shear strength of the welded portion, and a cross tension test value is treated as a peeling strength of the welded portion by two kinds of tests prescribed in JIS.

[0010] However, the shear strength and the peeling strength of the spot welding obtained by the test come under a structural influence such as a width. Therefore, the test value cannot help being corrected and estimated from various points of view in an actual member. In a system making an optimal design by a collision simulation of an automobile on a computer which is advancing rapidly in recent years, an estimation accuracy thereof is hardly adequate, and a reliability of the optimal design for a collision safety has been deteriorated.

[0011] An object of the present invention is to prevent the fracture of the welded portion of the member at the time of crash deformation, to thereby realize an optimization of a deformed buckling mode, and to improve the absorbed energy of the crash by judging a fracture prediction for the spot welded portion at the time of the crash deformation by an prediction model implemented in a finite element

method analysis, by the finite element method analysis on the computer not to use the experimental manufacturing of the member or the collision test.

[0012] Substances of the present invention are as stated below.

(1) A fracture prediction device for a spot welded portion, including: an input means inputting all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint plates in a tension test, based on a cross tension test and/or a shear tension test at a spot welded joint; a calculation means calculating a fracture strength parameter of the spot welded portion in a cross tension and/or a shear tension from all or any of the material strength, the plate thickness, the nugget diameter of the spot welding, the plate width of the joint, and the rotation angle of the joint in the tension test; a parameter storage means storing the fracture strength parameter by each steel type; and a calculation means judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(2) A fracture prediction device for a spot welded portion, including: an input means inputting all or any of a material strength, a plate thickness, a

nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test, based on a cross tension test and/or a shear tension test at a spot welded joint; a calculation means calculating a fracture strength parameter in a cross tension and/or a shear tension based on a fracture strength curve of a spot welded portion asked from all or any of the material strength, the plate thickness, the nugget diameter of the spot welding, the plate width of the joint, and the rotation angle of the joint in the tension test; a parameter storage means storing the fracture strength parameter by each steel type; and a calculation means judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture limit line in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(3) A fracture prediction method for a spot welded portion, including the steps of: inputting all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test, based on a cross tension test and/or a shear tension test at a spot welded joint; calculating a fracture strength parameter of the spot welded portion in a cross tension and/or a shear tension from all or any of the material strength, the plate thickness, the nugget diameter of the spot welding, the plate width

of the joint, and the rotation angle of the joint in the tension test; storing the fracture strength parameter by each steel type in a parameter storage means; and judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(4) A fracture prediction method for a spot welded portion, including the steps of: inputting all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test, based on a cross tension test and/or a shear tension test at a spot welded joint; calculating a fracture strength parameter in a cross tension and/or a shear tension based on a fracture strength curve of a spot welded portion asked from all or any of the material strength, the plate thickness, the nugget diameter of the spot welding, the plate width of the joint, and the rotation angle of the joint in the tension test; storing the fracture strength parameter by each steel type in a parameter storage means; and judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture limit line in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(5) A computer program for a fracture prediction of a spot welded portion for designing circuit including: program code means for calculating a fracture strength parameter of the spot welded portion in a cross tension and/or a shear tension from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test and/or a shear tension test at a spot welded joint; program code means for storing the fracture strength parameter by each steel type in a parameter storage means; and program code means for judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(6) A computer program for a fracture prediction of a spot welded portion for designing circuit including: program code means for calculating a fracture strength parameter of the spot welded portion in a cross tension and/or a shear tension based on a fracture strength curve of the spot welded portion asked from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test and/or a shear tension test at a spot

welded joint; program code means for storing the fracture strength parameter by each steel type in a parameter storage means; and program code means for judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture limit line in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(7) A computer readable recording medium recording a computer program for causing a computer to execute the steps, including: calculating a fracture strength parameter of a spot welded portion in a cross tension and/or a shear tension from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test and/or a shear tension test at a spot welded joint; storing the fracture strength parameter by each steel type in a parameter storage means; and judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(8) A computer readable recording medium recording a computer program for causing a computer to execute the steps, including: calculating a fracture strength parameter of a spot welded portion in a cross tension

and/or a shear tension based on a fracture strength curve of the spot welded portion asked from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width a the joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test and/or a shear tension test at a spot welded joint; storing the fracture strength parameter by each steel type in a parameter storage means; and judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture limit line in which a deformation at a periphery of the spot welding is modeled by a finite element method.

Brief Description of the Drawings

[0013] Fig. 1 is a view showing an outline of a method of a shear tension test;

Fig. 2 is a view showing an outline of a method of a cross tension test;

Fig. 3 is a side view at a testing time of the cross tension test;

Fig. 4 is a view showing an example of fracture strength curves;

Fig. 5 is a view showing a relation between a fracture limit line and calculated strengths Fn, Fs;

Fig. 6 is a view in which relations between a load and a displacement at a time of fracture in the shear tension test are compared between an experiment

and a simulation, that is FEM;

Fig. 7 is a view in which relations between a load and a displacement at a time of a fracture in the cross tension test are compared between an experiment and a simulation, that is FEM;

Fig. 8 is a block diagram showing an example of a computer system capable of configuring a fracture prediction device for a spot welded portion;

Fig. 9 is a view showing a fracture strength curve of an actual steel plate of 590 MPa grade, and a thickness of 1.8 mm;

Fig. 10 is a view showing a curvilinear relation of "α_1" and "d/W" idetified by an experiment;

Fig. 11 is a view in which relations between a load and a displacement at a time of fracture in the shear tension test with a high strength steel of 980 MPa grade, are compared between an experiment and a simulation (FEM);

Fig. 12A is a view showing a member shape of the high strength steel of 980 MPa grade used for a dynamic axial crush test;

Fig. 12B is a view showing a result in which a fractured appearance of the spot welded portion at the time of a dynamic axial crush test is simulated (FEM); and

Fig. 12C is a photograph showing the fractured appearance of the spot welded portion at the time of the dynamic axial crush test.

Detailed Description of the Preferred Embodiments

[0014] Hereinafter, preferred embodiments of the present invention are described with reference to the drawings. Fig. 1 is a view showing an outline of a method of a shear tension test. As a specimen, two steel plates being base materials 2 are overlapped and spot welded as shown in the drawing to form a nugget 1. A tension test for this specimen in directions shown by arrows 3 is performed until this specimen fractures. At this time, displacements and loads of the specimen in the tensile directions 3 are measured. The fracture occurs at a periphery of the nugget 1, and it becomes to be a maximum load at this time. This value is to be a fracture limit load "Ftss" (N). When it reaches this limit load "Ftss", a mean stress "σo" (MPa) inside of the base material is "Ftss/W·t" from a width "W" (mm) and a plate thickness "t" (mm) of the base material 2.

[0015] At the periphery of the nugget 1 to be a initiation point of the fracture, a stress concentration factor "α" at an end portion of the nugget 1 and the base materials 2 can be defined as shown in a formula (1) as a fraction of a tensile strength "TS" of the base material and the mean tensile stress "σo" of the base material when a maximum stress is assumed to reach the tensile strength "TS" (MPa).

$$\alpha = TS/\sigma o = TS \cdot W \cdot t/Ftss \ldots (1)$$

[0016] The fracture limit loads "Ftss" are measured

by materials with various tensile strengths "TS" and various specimen widths "W", plate thicknesses "t", and nugget diameters "d" (mm), and thereby, this stress concentration factor "α" is calculated from the formula (1) to create a table as a database. Herewith, the fracture limit load "Ftss" with an arbitrary tensile strength "TS", plate thickness "t", width "W", and nugget diameter "d" can be predicted with a formula (2) by using the stress concentration factor "α" in the table.

$$Ftss = TS \cdot W \cdot t/\alpha \quad \dots (2)$$

[0017] Besides, the stress concentration factor "α" becomes to be a curve by organizing with a fraction "d/W" of the nugget diameter "d" and the width "W". Therefore, the "Ftss" may be predicted from the formula (2) by using the "α" calculated from a formula (3).

$$\alpha = k/(p \cdot d/W - q)^n + r \quad \dots (3)$$

Here, the "k, p, q, n, and r" are parameters to perform a fitting of a curvilinear relation of the "α" and the "d/W" with the formula (3), and they are preferable to be in the ranges as follows: k = 0.001 to 100; p = 0.01 to 100; q = −10 to 10; n = 1 to 10; and r = −100 to 100. However, the formula to make the fitting of the curve is not necessarily to have a format of the formula (3), and it may be the formula capable of fitting the curvilinear relation. Besides, the "α" may be read from the graph of the curve directly without using the formula (3).

[0018] Next, a member in an arbitrary shape welded by the spot welding is modeled by using a finite element method on a computer. A shear force "Fs" (N) in a direction along a member surface of an element connecting members with each other in which the spot welding is modeled, and a vertical force "Fn" (N) in a direction connecting members with each other orthogonal to the shear force "Fs" (N) are calculated by the computer one after another during a deformation of a collision analysis reproduced by using the finite element method. This calculation means of the "Fs" and "Fn" depends on a general analysis code, for example, refer to "PAM-CRASH v2002 user's manual" made by ESI Co., Ltd.. A fracture judgment on the computer is set at the time when a formula (4) becomes true.

$$Fn^2 + Fs^2 \geqq Ftss^2 \quad \dots (4)$$

[0019] Fig. 2 is a view showing an outline of a method of a cross tension test. As the specimen, two steel plates being the base materials 2 are overlapped and spot welded as shown in the drawing to form the nugget 1. A tension test for this specimen is performed in the directions shown by the arrows 3 until this specimen fractures. At this time, the displacements and the loads of the specimen in the tensile directions 3 are measured. The fracture occurs at the periphery of the nugget 1, and it becomes to be the maximum load at this time. This value is set as a fracture limit load "Fcts" (N).

When it reaches this limit load "Fcts", the mean stress "σo" (MPa) inside of a plate surface of the base material is to be "Fcts/(2W·t·sin θ)" from the width "W" (mm) and the plate thickness "t" (mm) of the base material 2 by using an angle "θ" shown in Fig. 3.

[0020] At the periphery of the nugget 1 to be the initiation point of the fracture, the stress concentration factor "α" at the end portion of the nugget 1 and the base material 2 can be defined as shown in a formula (5) as the fraction of the tensile strength "TS" (MPa) of the base material and the mean tensile stress "σo" (MPa) of the base material if the maximum stress is assumed to reach the tensile strength "TS" (MPa).

$$\alpha = TS/\sigma o = TS \cdot W \cdot t/Fcts \ldots (5)$$

[0021] This is completely the same format as the formula (1) asked by the shear tension test, and an angle correction "θ" is added because the tensile directions are different. Consequently, the fracture limit load "Fcts" can be calculated by a formula (6) with an arbitrary material, width, plate thickness, and nugget diameter by the same method as the shear tension test.

$$Fcts = 2 \cdot TS \cdot W \cdot t \cdot \sin\theta/\alpha \ \ldots (6)$$

[0022] As same as the case in the shear tension, a fracture judgment of the spot welded portion in an arbitrary member at the time of the collision deformation is regarded to be at the time when a

formula (7) becomes true on the computer.

$$Fn \geqq Fcts \ldots (7)$$

[0023] As stated above, the fracture limit loads , that is fracture strength parameter "Ftss" and "Fcts" are calculated by the formula (1), formula (2), formula (3), formula (5), and formula (6), the collision deformation is analyzed by the finite element method with the arbitrary member, and the fracture judgment of the spot welding is set to be at the time when either the formula (4) or the formula (7) becomes true first or when they become true at the same time or one formula into which the formula (4) and formula (7) is combined becomes true.

[0024] When the form of the deformation is known from the shape of the member and an input method of the load, only one of the formula (4) or the formula (7) may be calculated on the computer to make a judge. Besides, the fraction between the "Fn" and the "Fs" is calculated on the computer one after another, and the fracture judgment may be made, for example, by using the formula (7) when Fn > 3Fs, and the formula (4) in other cases.

[0025] Herewith, it becomes possible to predict the fracture judgment of the spot welding on the computer accurately without verifying by creating the member and performing the collision test actually. It becomes possible to investigate a condition in which the spot welding does not fracture by varying the member shape, the material, the plate thickness, the

nugget diameter, and a welding position on the computer by using this method, and an optimal member can be designed.

[0026] As for the fracture limit load of the spot welding especially when the tensile strength "TS" of the material is larger than 590 (MPa), it is suitable to calculate the "Ftss" in the shear tension test by using the following formula (2'), formula (3m) instead of the formula (2), formula (3), and the "Fcts" in the cross tension test by using the following formula (3m2), formula (3m3), formula (3m4), and formula (6') instead of the formula (3), formula (6), different from the above-stated method.

$$Ftss = TS \cdot W \cdot t/\alpha_1 \quad \ldots (2')$$

$$\alpha_1 = (e\ (TS/f - g)^h - i)/(d/W)^j + 1 \quad \ldots (3m)$$

Here, the "e, f, g, h, i, and j" are parameters to perform a fitting of a curvilinear relation of the "α_1" and the "d/W" with the formula (3m), and they are within the ranges as follows: e = 0.0001 to 100; f = 100 to 2500 (MPa); g = 0.1 to 10; h = 0.0001 to 10; i = 0.01 to 100; and j = 1 to 100.

$$Fcts = 2 \cdot TS \cdot W \cdot t \cdot \sin\theta/\alpha_2 \quad \ldots (6')$$

$$\alpha_2 = \beta/(d/W)\chi + \delta \quad \ldots (3m2)$$

$$\chi = \phi\ (TS/\gamma - \eta)\ \Psi - \xi \quad \ldots (3m3)$$

$$\delta = \lambda\ (TS/\mu - \rho)\ \omega - \zeta \quad \ldots (3m4)$$

Here, the "β, χ, δ, ϕ, γ, η, Ψ, ξ, λ, μ, ρ, ω, and ζ" are parameters to perform a fitting of a curvilinear relation of the "α_2" and the "d/W" with the formula (3m2), formula (3m3), and formula (3m4),

and they are within the ranges as follows: β = 0.0001 to 100; ϕ = 0.1 to 100; γ = 100 to 2500 (MPa); η = 0.1 to 10; Ψ = 0.0001 to 100; ξ = 0.01 to 100; λ = 0.01 to 100; μ = 100 to 2500 (MPa); ρ = 0.1 to 10; ω = 0.0001 to 100; and ζ = 0.01 to 100.

[0027] The formula to make the fitting of the curve is not necessarily to be the formats of these formulas, and it is good enough as long as it can make the fitting of the curvilinear relation. Besides, the curvilinear relation of the "α_1" or the "α_2" and the "d/W" becomes one curve by each strength grade without using these formulas, and therefore, the "α_1" or the "α_2" can be identified directly from each graph of the curve.

[0028] Fig. 4 is a view schematically showing a method to calculate the fracture limit load by using a graph based on experimental data, in addition to the method to calculate the fracture limit load by using the formulas such as the formula (1), formula (2), formula (3), and formula (5), formula (6), or the formula (3m), formula (3m2), formula (3m3), and formula (3m4) instead of the formula (3). The fracture limit loads are measured by the test in which the "d/W" is varied and when it is graphed, the fracture load curves can be written in various curvilinear relations depending on the material strength TS. Here, the material strengths are TS1 < TS2 < TS3. The fracture limit load corresponding to the condition can be identified from these curves

directly. This curve becomes a fracture limit load curved surface by taking the plate thickness "t" as a third axis, and the fracture limit load can be identified by reading a value on the curved surface at an arbitrary plate thickness "t", the material strength "TS", the width "W", and the nugget diameter "d".

[0029] Further, a fracture limit line is created as shown in Fig. 5 by using the fracture limit loads identified by the various rotation angles "θ" instead of using the formula (4) and formula (7). This fracture limit line and the "Fn", "Fs" calculated one after another by the analysis of the finite element method are compared, and it may be judged as the fracture when the "Fn", "Fs" come to on the curve and at outside of the curve.

[0030] This method can be applied not only to steel material but also to every material. Besides, it can be applied not only to every welding such as a laser welding, an arc welding, a seam welding, and a mash-seam welding, but also to the spot welding, and further, to every mechanical bonding such as a TOX bonding and a rivet bonding, a friction bonding, a diffusion bonding, a friction diffusion bonding, a friction stir welding and every bonding by using an adhesive agent. The calculation method on the computer can be applied to a boundary element method, a difference method, a meshless method, an elementary analysis, and every calculation method without

limiting to the finite element method, and it can be applied to a calculation method independent of a material mechanics and a computer.

[0031] The calculation method of the stress concentration factor "α" by means of the experiment is not also limited to the above-stated shear tension test, cross tension test, and it can be calculated by using every shape of specimen, and a load applying method.

[0032] The above-stated prediction of the fracture judgment can be applied not only to the collision analysis of the whole automobile and member, but also to components other than the automobile, and it goes without saying that it can be applied to an analysis in a quasi-static deformation other than a collision.

[0033] Fig. 8 is a block diagram showing an example of a computer system capable of configuring a fracture prediction device for a spot welded portion. In the drawing, reference numeral 1200 is a computer PC. The PC 1200 includes a CPU 1201, executes a device control software stored in a ROM 1202 or a hard disk (HD) 1211, or supplied from a flexible disk drive (FD) 1212, and totally controls respective devices connected to a system bus 1204.

[0034] Respective function means of the present embodiment are constituted by programs stored in the above-stated CPU 1201, ROM 1202, or hard disk (HD) 1211 of the PC 1200.

[0035] Reference numeral 1203 is a RAM, and it

functions as a main memory, a work area, and so on of the CPU 1201. Reference numeral 1205 is a keyboard controller (KBC), and it controls to input signals inputted from a keyboard (KB) 1209 to the system main body. Reference numeral 1206 is a display controller (CRTC), and it performs a display control on a display device (CRT) 1210. Reference numeral 1207 is a disk controller (DKC), and it controls an access with the hard disk (HD) 1211 and the flexible disk (FD) 1212, storing a boot program (a program starting an execution (operation) of hardwares and softwares of a personal computer), plural application programs, edit files, user files, network management programs, and so on.

[0036] Reference numeral 1208 is a network interface card (NIC), and it performs interactive data exchanges with a network printer, other network devices, or other PCs via a LAN 1220.

[0037] The above-stated functions of the embodiment can also be realized by the execution of the program by the computer. Besides, means to supply a computer with the computer program, for example, a computer readable recording medium such as a CD-ROM and so on recording such program, or a transmission medium such as an internet transmitting such program can be applied as the embodiment of the present invention. Besides, a computer program product such as the computer readable recording medium recording the above-stated program can also be applied as the

embodiment of the present invention. The above-stated computer program, recording medium, transmission medium, and computer program product are included within a range of the present invention. As the recording media, for example, a flexible disk, a hard disk, an optical disk, a magnetic optical disk, a CD-ROM, a magnetic tape, a nonvolatile memory, a ROM, and so on can be used.

[0038] (Example 1)

A system is structured in which the above-stated fracture prediction model is used, and a fracture of a spot welded portion is judged automatically while analyzing a collision deformation of a member, as a subroutine program in a general collision analysis FEM code. The used code is "PAM-CRASH v2002" made by ESI Co., Ltd., and the spot welded portion is modeled by using a "Multi-PLINK" as for the member modeled by a shell element.

[0039] A comparison of an analysis, in which a shear tension test and a cross tension test are modeled as they are, and an experiment is the best for an accuracy verification of the fracture prediction model, because an exact comparison becomes possible. Therefore, a shear tension specimen and a cross tension specimen are created with a steel plate of 590 MPa grade and a thickness "t" = 1.8 (mm), according to JIS standards of 3136, 3137. A nugget diameter of the spot welding is $5\sqrt{t}$ (mm). A test is performed by using an Instron type testing machine,

and loads and displacements until a spot welded portion fractures are measured at that time. At the same time, the shear tension test and the cross tension test in the same forms as the test are modeled on the computer, an analysis of the tension test is performed by the FEM code mounting the above-stated subroutine program to judge the fracture of the spot welded portion automatically, and the loads and the displacements until the spot welding fractures as same as the experiment are calculated. Inputted initial parameters of "TS" = 642 (MPa), "t" = 1.8 (mm), "d" = 6.7 (mm), "θ" = 23°, are set as common parameters. In the shear tension test, the following values are used.

"α" = 1.80 (-), "W" = 40 (mm)

In the cross tension test, the following values are used.

"α" = 2.17 (-), "W" = 50 (mm)

The fracture strength parameters "Ftss" = 25680 (N), "Fcts" = 20798 (N) obtained by the above are installed in a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by the finite element method, to thereby judge the fracture of the spot welded portion.

[0040] The test model is created by the shell element of which collision analysis level of a full vehicle is rough, and a boundary condition is also simplified with considering that they can be applied for the collision analysis of an actual member.

[0041] Fig. 6 and Fig. 7 are verification examples of this system. Reference numeral 4 represents a simulation of a shear tension specimen, and reference numeral 5 represents a simulation of a cross tension specimen. Fracture modes are respectively different in the shear tension test and the cross tension test. However, it turns out that the fracture loads on the load - stroke curves of the experiment and the FEM analysis are matched. In the shear tension test, it seems that the shapes of the load - displacement curves until they reach the fracture load are different between in the experiment and the analysis. However, they just seem different because a specimen chuck is connected to a crosshead via a universal joint in the experiment, and therefore, a rotation of the chuck portion occurs at a time of load rising, but this rotation is not considered in the analysis because of the simplification of the model. This may just change a behavior of an initial stroke change, and therefore, it does not essentially affect on the load at the time of the fracture occurrence. Behaviors of the load - displacement curves are slightly different between in the experiment and in the analysis also in the cross tension test, but it is similarly a problem of the chuck of the experiment. Therefore, it only affects on the initial behavior and the experiment and the analysis are matched at the fracture loads. Of course, if it is modeled with including the chuck portion on the analysis, the

behavior of this portion may be matched with the experiment, but here, it is skipped because it is not an essential problem. This rather shows the following that it is possible to predict the spot fracture accurately in an analysis at practical level in which detailed portions are simplified in a large-scaled collision analysis of an entire model or a partial model of the full vehicle, because the fracture load of an actual test can be predicted accurately even by the FEM analysis in which the test is modeled in a simple manner.

[0042] As stated above, it can be verified that this is the analysis method capable of predicting the fracture of the spot welding accurately by a basic test. Besides, the prediction of the spot welding fracture at the time of the collision deformation in a component level is verified from both experimental side and analysis side, and it is confirmed that the fracture prediction in the analysis is matched with the experiment. The system is confirmed to be a system capable of controlling and designing a deformation mode of members and an absorption energy based on the above, because the fracture of the spot welded portion can be predicted.

[0043] This method can be installed to general solvers such as "LS-DYNA3D" made by LSTC Co., Ltd., "RADIOSS" made by MECALOG Co., Ltd., and to a solver developed individually, in addition to the general solver "PAM-CRASH". Besides, the model of the spot

welded portion is applicable for a beam element, a shell element, a solid element, and so on, in addition to a contact type such as the "Multi-PLINK".

[0044] (Example 2)

Next, a verification of a prediction accuracy of a shear tensile strength is performed by using a fracture strength curve. Material thereof is a steel plate of 590 MPa grade, a thickness = 1.8 (mm) as same as in the example 1. At first, a width "W" of a specimen of the shear tension test is varied from 20 (mm) to 50 (mm), at the same time, a nugget diameter "d" is also varied from 4 (mm) to 7 (mm) to perform the test, and a fracture strength parameter "Ftss" is actually measured. A fracture strength curve shown in Fig. 9 can be obtained from the results of the test. The fracture strength parameter "Ftss" = 25.5 (kN) can be read from the fracture strength curve as shown by a circular sign in Fig. 9, under a condition of "d" = 6.7 (mm), "W" = 40 (mm) which is the same condition as in the example 1. This is approximately the same value with the "Ftss" under the same condition in the example 1. It can be confirmed that the fracture loads are matched on the load - stroke curves of the experiment and the FEM analysis as shown in Fig. 6, by performing a finite element method (FEM) analysis in the following, in which the test is modeled as same as in the example 1. Consequently, it shows that the fracture strength parameters under any condition in practical use can

be obtained by creating the fracture strength curve with varying the width "W" and the nugget diameter "d" within a wide range corresponding to the actual use. The case when the material strength and the plate thickness are fixed is shown in the above, but when the strength and the plate thickness vary, the fracture strength curves are to be created respectively.

[0045] (Example 3)

Next, a system is structured in which a fracture prediction model when a tensile strength thereof is larger than 590 MPa grade is used, and a fracture of a spot welded portion is automatically judged while analyzing a collision deformation of a member as a subroutine program in the general collision analysis FEM code. The used code is "PAM-CRASH v2003" made by ESI Co., Ltd., and the spot welded portion of a member which is modeled by a shell element is modeled by using "Multi-PLINK".

[0046] A comparison of an analysis, in which the shear tension test is modeled as it is, and an experiment is the best for an accuracy verification of the fracture prediction model, because an exact comparison becomes possible. Therefore, a shear tension specimen is created with a steel plate of 980 MPa grade and a thickness "t" = 1.4 (mm) as same as in the example 1. A nugget diameter of the spot welding is $6\sqrt{t}$ (mm). A test is performed by using an Instron type testing machine, and the loads and the

displacements until the spot welded portion fractures are measured. At the same time, the shear tension test in the same form as the test is modeled on the computer, an analysis of the tension test is performed by the FEM code mounting the above-stated subroutine program to judge the fracture of the spot welded portion automatically, and the loads and displacements until the spot welding fractures as same as the experiment are calculated. Inputted initial parameters of "TS" = 983 (MPa), "t" = 1.4 (mm), "d" = 7.2 (mm), "θ" = 23°, "α_1" = 2.12 (-), and "W" = 40 (mm) are used. The "α_1" is determined by reading from a graph of the curve of the "α_1" and the "d/W" asked by the experiment as shown in Fig. 10. A fracture strength parameter "Ftss" = 26340 (N) obtained by the above is installed to a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method, to judge the fracture of the spot welded portion.

[0047] The test model is created by a shell element of which collision analysis level of a full vehicle is rough, and a boundary condition is also simplified with considering that they can be applied for the collision analysis of an actual member.

[0048] Fig. 11 is a verification example of this system, and it can be seen that the fracture loads on the load - stroke curves of the experiment and the FEM analysis are matched in the shear tension test.

It seems that the shapes of the load - displacement curves until they reach the fracture loads are different between the experiment and the analysis in the shear tension test, but the cause is the same as the one stated in the example 1 and there is no problem.

[0049] Further, a verification of a prediction model is performed by an axial crush test of a simple member. As shown in Fig. 12A, a member 6 is constituted by a spot welding of a hat shape in cross section and an attached closure plate, and a hat top portion, perpendicular walls are 50 (mm) respectively, flanges are 20 (mm), and a length in a crush direction is 300 (mm). Material used for the member is a steel product of 980 MPa grade as same as the above, and the nugget diameter of the spot welding is $4\sqrt{t}$ (mm). A dynamic crush test is performed under a condition that a weight of a drop hammer is 500 (kg), an initial speed at the time of the crush is 6 (m/s), and the FEM analysis is performed under the same condition. The test result and the FEM analysis result are compared by the shapes of the members after the crush as shown in Fig. 12B showing a simulation 7, and Fig. 12C showing an actual experiment. As a result, shapes of buckling are the same, and in particular, both patterns are matched in which the spot welded portion fractures, and thereby, the attached closure plate is detached. Herewith, it is shown that the spot fracture can be predicted

accurately by an analysis at practical level in which detailed portions are simplified, in a large-scaled collision analysis of an entire model and a partial model of a full vehicle.

Industrial Applicability

[0050] According to the present invention, it is possible to perform a fracture prediction accurately at a portion in which, for example, a spot welding of an automobile member is modeled by a finite element method analysis on a computer. Therefore, a verification of the fracture of the spot welded portion at a time of a collision test by using an actual automobile member can be skipped, or the number of times of the verification test can be reduced drastically. Besides, for example, experimental manufactures with varying a spot welding condition of the automobile member, a member design preventing the spot welding fracture by means of a large-scaled experiment of a collision test, can be replaced by a design preventing the fracture of the spot welded portion by the collision analysis on the computer, and therefore, it is possible to contribute to a significant cost reduction and a shortening of a design and development period.